Auditory Masking Patterns in Bottlenose Dolphins from Anthropogenic and Natural Noise Sources

Brian K. Branstetter
National Marine Mammal Foundation
2240 Shelter Island Dr., #200
San Diego, CA 92106
phone: (808) 779-3077 fax: (619) 773-3153 email: brian.branstetter@nmmpfoundation.org

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http://nmmpfoundation.org/

LONG-TERM GOALS

The long-term goals of this project are to better understand and predict auditory masking in odontocetes with realistic, environmental noise types. Current predictions based on Gaussian noise masking will be improved upon.

OBJECTIVES

The objectives of this effort are to understand and predict how environmental noise (both anthropogenic and natural) affects detection, discrimination, and recognition abilities of odontocete cetaceans. The specific objectives for FY13 were to:

- Complete statistical models of auditory masking
- Report results in peer reviewed journals and professional conferences

APPROACH

The primary goal of the current project is to better understand auditory masking by determining masking patterns for a broad variety of environmental noise types, and define the mechanisms that govern auditory signal processing in environmental noise. Behavioral threshold methods developed at SSC San Diego (Finneran, Carder, Schlundt, & Ridgway, 2005) allow thresholds to be obtained rapidly (i.e., less than four minutes). Behavioral thresholds are measured using a psychophysical technique, such as modified up/down adaptive staircase. The procedure for estimating masked thresholds is identical to a standard behavioral hearing test except masking noise is played continuously during the threshold estimation procedure.

Task 1. Statistical model of auditory masking
Metrics related to the frequency spectrum of noise (e.g., critical ratios) are often used to describe and predict auditory masking. For this task, detection thresholds for a 10 kHz tone were measured in the presence of anthropogenic, natural, and synthesized noise. Time-domain and frequency-domain metrics were calculated for the different noise types (see Table 1), and regression models were used to

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determine the relationship between noise metrics and masked tonal thresholds. Most metrics were common acoustic or statistical measures. However the comodulation index was fabricated to measure across-channel envelope coherence (FIG 1), based on experiments conducted in FY2010 - FY2012.

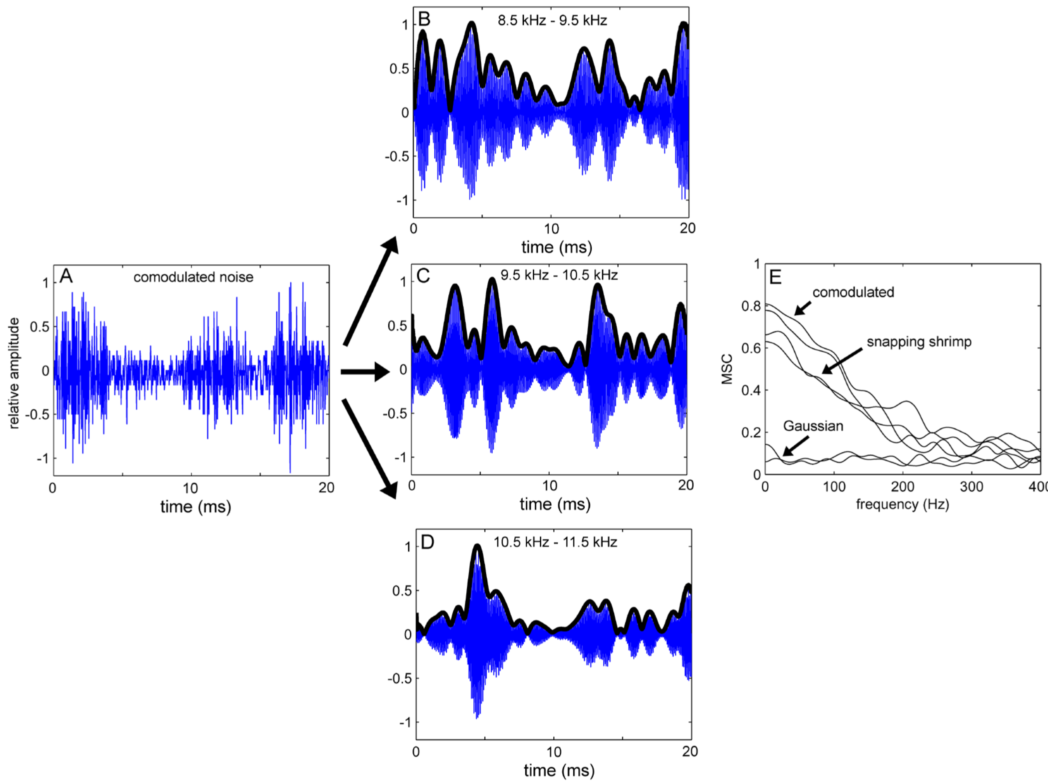

FIG. 1. Processing stages to calculate the comodulation index. The noise (panel A) is bandpass filtered into a signal (S) band, a low frequency (LF) band, and a high frequency (HF) band (waveforms in panels B, C, and D, respectively). The Hilbert envelope is extracted from each band of noise (thick lines in panels B, C, and D). The magnitude squared coherence (MSC) is calculated between the Hilbert envelopes from the S band and LF band, and again between the S and HF bands. Panel E displays the MSC as a function of frequency for three noise types. Each function is the average of five 100-ms segments. Each noise type has two functions because the S band is compared to both the LF and HF bands. Noise that is comodulated has higher MSC at the lower frequencies. The CI is calculated by selecting the largest MSC for a given noise type, regardless of the frequency.

Table 1. Metrics used as predictor variables in the regression models

Waveform	Spectrum	Temporal Envelope
peak pressure (P)	pressure spectral density (PSD) level	envelope standard deviation (ESD)
peak-peak pressure (PP)		envelope kurtosis (EKURT)
root mean square pressure (RMS)		comodulation index (CI)
kurtosis (KURT)		

Key personnel
Key personnel for FY2013 have been Brian Branstetter Ph.D. (PI) who participated in all aspect of this study. Kimberly Bakhtiari, Hitomi Aihara, Amy Black and Keri Wickersham helped with animal training and data collection. James Finneran Ph.D developed custom Labview software.

WORK COMPLETED

Statistical model of auditory masking
Regression models were used to determine the relationship between sound metrics and auditory thresholds for a variety of noise types. The threshold experiments were previously conducted between 2007 – 2012.

Publications and presentations
Two manuscripts have been published in 2013 (see publications below). A third manuscript has been conditionally accepted for publication. A fourth manuscript is in print. Two more manuscripts are in preparation and at least one of these is expected to be published before the end of 2013. Results from this project were presented at the 3rd International Conference on the Effects of Noise on Aquatic Life (Budapest, 08/2013) and at the Marine Mammal Hearing Workshop (San Diego, 09/2013). An additional presentation is scheduled for the Acoustical Society of America (San Francisco, 12/2013).

RESULTS

Statistical model of auditory masking
The most parsimonious model that described the bulk of the masking data was an exponential decay function of the form:

$$y = b_1 PSD + b_2 e^{-CI/b_3} \tag{5}$$

where y is the predicted threshold, and b_1, b_2, and b_3 are parameter estimates. FIG. 2 displays the model as a surface where $b_1 = 1.13$, $b_2 = 32.84$, and $b_3 = 0.24$. The data points represent masked thresholds from three dolphins with 12 different noise types. Analysis of the residual errors (FIG 3) demonstrates that the two-parameter model produces much better fits than critical ratio predictions, while still being simple and parsimonious.

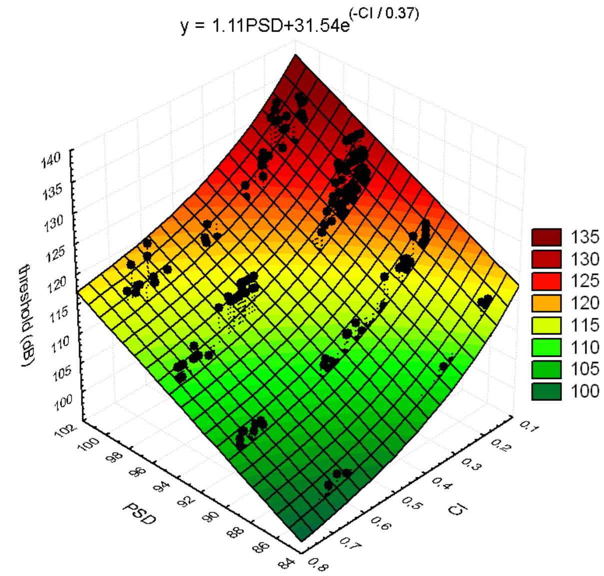

FIG 2. Surface plots of a regression model where thresholds are a function of CI and PSD. Black points represent threshold data.

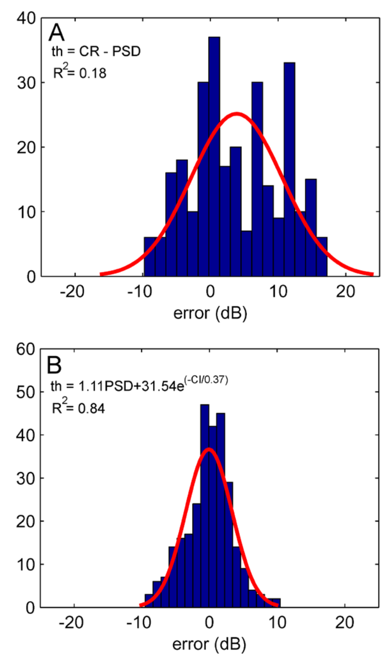

FIG. 3. Histogram of error distribution from two models used to predict auditory masking. A) Error distribution for a critical ratio model. B) Error distribution from an exponential decay model with PSD and CI as predictors. The model in B) provides more accurate predictions.

IMPACT/APPLICATIONS

The main conclusion that can be drawn from the statistical analysis:

1. Masked detection thresholds can be better predicted from models with both PSD and CI as predictors.

Most models of auditory masking in marine mammals rely on a single metric related to noise spectrum levels (e.g., critical ratios, 1/3 octave band levels, spectral density levels). All time domain metrics related to noise are discarded. This approach is convenient. However, the data presented here and from FY10 - FY12 demonstrate that noise with equal spectrum levels can result in thresholds that vary by as much as 22 dB. The CI of the noise in conjunction with PSD provides a much more accurate description of auditory masking for the bottlenose dolphin.

RELATED PROJECTS

NONE

REFERENCES

Branstetter, B. K., & Finneran, J. J. (2008). Comodulation masking release in bottlenose dolphins (*Tursiops truncatus*). *Journal of the Acoustical Society of America, 124*(1), 625-633.

Branstetter, B. K., Trickey, J. S., Bakhtiari, K., Black, A., Aihara, H., & Finneran, J. J. (2013). Auditory masking patterns in bottlenose dolphins (*Tursiops truncatus*) with natural, anthropogenic, and synthesized noise. *J Acoust Soc Am, 133*(3), 1811-1818.

Finneran, J. J., Carder, D. A., Schlundt, C. E., & Ridgway, S. H. (2005). Temporary threshold shift (TTS) in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. *Journal of the Acoustical Society of America, 118*(4), 2696-2705.

Trickey, J. S., Branstetter, B. B., & Finneran, J. J. (2011). Auditory masking with environmental, comodulated, and Gaussian noise in bottlenose dolphins (*Tursiops truncatus*). *Journal of the Acoustical Society of America, 128*(6), 3799-3804.

PUBLICATIONS

Branstetter, B. K., Trickey, J. S., Aihara, H., and Finneran, J. J., Liberman, T. R. (In Review). “Time and frequency metrics related to auditory masking of a 10 kHz tone in a bottlenose dolphin (Tursiops truncatus).” J. Acoust. Soc. Am.

Finneran, J. J., and Branstetter, B. K., (In Press). “Effects of noise on sound perception in marine mammals.” In: Animal Signals and Communication. Springer-Vergal, New York. [IN PRESS, REFEREED]

Branstetter, B. K., Black, A., Bakhtiari, K., (2013). “Discrimination of mixed-directional whistles by a bottlenose dolphin (Tursiops truncatus).” J. Acoust. Soc. Am., 134, 2274 – 2285. [PUBLISHED, REFEREED].

Branstetter, B. K., Trickey, J. S., Black, A., Aihara, H., and Finneran, J. J. (2013). "Auditory masking patterns in bottlenose dolphins (*Tursiops truncates*) with natural, anthropogenic, and synthesized noise." J. Acoust. Soc. Am., 133, 1811-1818. [PUBLISHED, REFEREED].

Branstetter, B. K., Finneran, J. J., Fletcher, E. A., Weisman, B. C., Ridgway, S. H. (2012). "Dolphins can maintain vigilant behavior through echolocation for 15 days without interruption or cognitive impairment." PLoS ONE [PUBLISHED, REFEREED]

Branstetter, B. K., Moore, P. W., Finneran, J. J., Tormey, M. N., Aihara, H. (2012). "Directional properties of bottlenose dolphin (*Tursiops truncatus*) clicks, burst-pulse and whistle sounds." J. Acoust. Soc. Am. 131, 1613-1621 [PUBLISHED, REFEREED].

Au, W. W. L., Branstetter, B. K., Moore, P. W., Finneran, J. J. (2012). "Dolphin biosonar signals measured at extreme off-axis angles: Insights to sound propogation in the head." J. Acoust. Soc. Am. 132, 1199-1206 [PUBLISHED, REFEREED].

Mooney, T. A., Yamato, M., Branstetter, B. K. (2012). "Hearing in cetaceans: from natural history to experimental biology." Adv. Mar. Bio. 63, 197-246 [PUBLISHED, REFEREED].

Au, W. W. L., Branstetter, B. K., Moore, P. W., Finneran, J. J. (2012). "The biosonar field around an Atlantic bottlenose dolphin (*Tursiops truncatus*). J. Acoust. Soc. Am. 131, 569-576 [PUBLISHED, REFEREED].

Lemonds, D. W., Kloepper, L. N., Nachtigall, P. E., Au, W. W. L., Vlachos, S. A., and Branstetter B. K. (2011). "A re-evaluation of auditory filter shape in delphinid odontocetes: Evidence of constant-bandwidth filters." J. Acoust. Soc. Am. 130, 3107 [PUBLISHED, REFEREED].